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THE ESCAPE OF GAS FROM COAL

BY

HORACE C. PORTER

AND

F. K. OVITZ

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CONTENTS.

Page.
General statement 3
Significance of results 3
Condition of the gas in coal 4
Previous investigations 5
Summary and interpretation of results 6
Procedure in experiments 8
Loss of heating value 13
Conclusions 13
Publications on fuel testing 13

ILLUSTRATIONS.

Page.
Figure 1. Rate of escape of methane from coal 11

THE ESCAPE OF GAS FROM COAL.

By Horace C. Porter and F. K. Ovitz.

GENERAL STATEMENT.

It is a matter of common knowledge that inflammable gas made up chiefly of methane, which forms with air the so-called fire damp of the miner, escapes from the coal in many mines; yet little is known as to the condition of this gas in the coal, its quantity and rate of escape. In addition to the gas set free by the coal itself, there is in many mines a large amount of inflammable gas that comes from reservoirs in the rock strata above or below the coal bed and enters the mine through cracks in the roof or floor. Gas entering the mine in such manner from extraneous sources is not considered in the following report, which presents rather some results of a laboratory investigation of the rate of escape of gas from several coals while kept in bottles connected to gas-collecting reservoirs. This investigation was begun by the United States Geological Survey and is being continued by the Bureau of Mines at the mining experiment station at Pittsburg, Pa.

SIGNIFICANCE OF RESULTS.

The results of the investigation show that gas escapes from coal not only during the breaking down of the coal in the mines, but also continuously for a long time after the coal is mined. The volume from some coals is so great as to merit serious consideration in connection with the ventilating of the mines and the choice of methods of breaking down the coal. For example, during the first two weeks after mining, there was set free by one coal, exclusive of the gas that escaped during mining, a volume of methane equal to three-fourths of the volume of the coal itself.[a] Probably each cubic foot of this coal (in the seam) set free in all during its mining and during the first two weeks thereafter a cubic foot of methane. It was shown by further test that during the first five months after mining there was set free from this coal a volume of methane equal to one and three-fourths times the volume of the coal.

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[a] See footnote, p. 10, for explanation of volume relations.

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Many investigators, Chamberlin,[a] among others, have shown that methane accumulates along lines of fracture, such as joint cracks, or in places of increased porosity in the coal bed and escapes from these as they are cut in mining. In any locality of the mine where for any reason adequate ventilation is not maintained, the methane which has thus escaped may become a source of danger from explosion.

CONDITION OF THE GAS IN COAL.

In some cases the volume of gas liberated from broken coal is greater than the volume of the coal itself—that is, of the actual solid and the cellular space combined. Several theories have been proposed to account for this fact. If the inclosed gas is mechanically imprisoned in the microscopic pores of the coal, it must be under a pressure greater than that of the atmosphere; otherwise it would occupy after its escape a volume less than that of the coal. It is possible, furthermore, that there is a continual slow formation of methane by chemical decomposition of the coal, or it may be that the gas is held in a state of occlusion—that is, either dissolved molecularly or adsorbed upon the inner surfaces of the cellular spaces.

The gas which escapes from coal has been very often called "occluded gas," but, as Chamberlin has made plain,[b] the word "occluded" has been loosely used in this connection, and the radical difference between mechanical imprisonment and true occlusion or condensation has been generally overlooked. The word "occlusion" properly implies the condensation of a gas within a solid substance to a state approaching that of liquid or solid, either condensed upon the interior surfaces of the pores or dissolved molecularly in the solid. The Century Dictionary defines occlusion as the absorption of a gas by a metal, as of hydrogen by palladium, in which case the hydrogen is regarded as existing in a solid form as a quasi metal. Mendeleeff[c] states, "The capacity of certain dense metals for the absorption of hydrogen * * * is termed occlusion and presents a similar phenomenon to solution; it is based on the capacity of metals of forming unstable, easily dissociating compounds with hydrogen similar to those which salts form with water."

The results presented in this paper do not determine the condition of the gas in coal. The fact that the gas escapes without the aid of heat or of reduced pressure is hardly in strict agreement with the accepted idea of occlusion. But, on the other hand, Chamberlin[d] found that during the crushing of coal to 30-mesh size under a high vacuum there was liberated only about one-quarter of the total volume of methane obtained from the same coal while bottled for six months in vacuo. This fact is with difficulty explained by the theory of mechanical imprisonment under pressure, for it seems likely that in such case the walls confining the gas would be broken by the large excess of pressure within, and that the bulk of the gas would escape immediately. The theory that methane continues to be formed by slow decomposition of the coal explains satisfactorily many of the phenomena observed, but does not easily account for the decrease in the rate of escape of the methane.

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[a] Chamberlin, R. T., Notes on explosive mine gases and dusts, with special reference to the explosions in the Monongah, Darr, and Naomi Coal Mines, U. S. Geol. Survey Bull. 383, 1909, p. 32.

[b] Op. cit., pp. 16–17.

[c] Mendeleeff, D. I., Principles of Chemistry, English Translation of 6th Edition, vol. 1, p. 143.

[d] Op. cit., pp. 34–36.

Whatever may be the condition of the gas and its manner of liberation, the results presented in this paper clearly establish the fact that methane continues to escape from coal in considerable quantities and for a long period under atmospheric conditions of temperature and pressure. If allowed to accumulate, this slowly escaping methane in mines may become a source of danger even greater than the methane liberated in breaking down the coal. Calculations based on these results show further that contrary to common opinion the loss of heat value due to loss of methane in exposed piles of coal is probably in all cases so small as to be almost inconsiderable.

PREVIOUS INVESTIGATIONS.

Parr and Wheeler[a] have noted the accumulation of combustible gas from Illinois coals in laboratory sample bottles kept sealed for a year. They attribute to this fact part of the loss of heat value which they found in these samples. Many investigations have been made of the so-called occluded gas in coal, notably by Bedson,[b] McConnel,[c] Trobridge,[d] Parr and Barker,[e] and Chamberlin.[f] With the exception of Chamberlin these investigators have confined their attention to the gases drawn from coal by a reduction of pressure during a comparatively brief space of time. Their findings as to the quantity and the composition of the gases vary widely. The discrepancies are probably due not only to differences in the character of the coals, but also to the fact that most of the investigators have taken little account of the gas that escaped in the interval between mining and testing. Parr and Barker took account of this factor by collecting 200-gram samples in flasks sealed in the mine and extracting the gases under vacuum on reaching the laboratory. They obtained in this manner from one Illinois coal 40 to 80 c. c. of methane and about 10 c. c. of carbon dioxide per 100 grams of coal, and showed also the rapid absorption of oxygen by fresh coal. Their experiments, however, did not take account of the gas liberated in breaking down the coal, nor did they study the escape of gas into an open space through an extended period of time. Chamberlin,[a] on the other hand, went further and not only extracted the loosely held gas of coal by crushing small lumps in a vacuum, but collected also considerable additional quantities of gas by keeping the crushed coal in a vacuum for six months. By crushing in vacuo to 10-mesh size coal from Monongah, W. Va., he obtained a volume of methane amounting, in different experiments, to 0.1 to 0.4 times the volume of the coal, and by keeping the crushed coal six months in vacuo he obtained an additional volume of methane 0.8 to 1.4 times the volume of the coal. The gas liberated in mining and during the transit of the coal in covered cans to the laboratory was disregarded. Other gases extracted in Chamberlin's experiments were carbon dioxide (less than one-tenth of the volume of methane), and very small quantities of carbon monoxide and unsaturated hydrocarbons.

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[a] Illinois State Geol. Survey Bull. No. 8, 1907, p. 168.

[b] Chem. News, vol. 68, 1893. p. 187.

[c] Jour. Soc. Chem. Ind., vol. 13, 1894, p. 25.

[d] Jour. Soc. Chem. Ind., vol. 25, 1906. p. 1129.

[e] University of Illinois Eng. Exp. Sta. Bull. 32, 1909, pp. 10–28.

[f] Op. cit., pp. 16–39.

SUMMARY AND INTERPRETATION OF RESULTS.

The experiments described in this paper supplement Chamberlin's work, and bring out the additional fact that methane and small quantities of carbon dioxide escape from coal for an extended period under atmospheric pressure, the amount of the gas and its rate of escape being nearly the same as when the coal is kept in a vacuum. Furthermore, the experiments show that oxygen is absorbed rapidly by fresh coal and in quantities which are far out of proportion to the carbon dioxide liberated, if the latter be assumed to arise from combustion of the coal. The tabular statements and graphs on succeeding pages show the rate at which methane is liberated from several different coals.

Unfortunately, the results do not permit even an approximate estimate of the rate at which the different coals absorb oxygen. It was found late in the course of the experiments that the concentration of the oxygen available for action on the coal had much influence on the rapidity of the action, and this concentration had varied decidedly in the different tests. Ordinary air was used in some of the tests and oxygen, 95 per cent pure, in others. In all the experiments there is clearly shown, however, a rapid and long-continued absorption of oxygen, with little or no accompanying formation of carbon dioxide. Later experiments, now in progress in the laboratory of the Bureau of Mines, show that coals vary widely in the rapidity with which they absorb oxygen under like conditions.

The rapid absorption of oxygen by fresh coal without the formation of carbon dioxide is well illustrated by the coal from Connellsville, Pa. (No. 41, Table 2, p. 10.) Ten kilograms (22 pounds) of this coal absorbed during the first day after mining nearly half the oxygen in the 10 liters of air in the bottle and gave off little more than one-tenth as much carbon dioxide as would have been formed if all of the oxygen absorbed had combined with carbon to produce carbon dioxide.

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[a] U. S. Geol. Survey, Bull. 383, pp. 17-39.

The air of a closed mine, or of a poorly ventilated section of any coal mine, is usually deficient in oxygen, as compared with normal air, and contains much less carbon dioxide than will account for this deficiency on the basis of the reaction of carbon and oxygen to form carbon dioxide.

This phenomenon is probably a direct result of the chemical addition of oxygen to the coal, since it is not likely that oxygen could be consumed in any other way without forming carbon dioxide, unless there were a fire in the mine, in which case oxygen would combine with hydrogen as well as with carbon. The oxygen absorbed from air by coal probably does not form directly either carbon dioxide or water, but is merely added, as suggested by Boudouard[a] and others, to certain compounds in the coal that are unsaturated with respect to oxygen and thereby produces humic acid or related substances.

The results presented show large variations in the quantities of methane liberated by the coals tested. A Kentucky cannel yielded only a trace of methane in nine months, while the Harrisburg, Ill., coal gave off one-fourth of its volume in four days, and the Monongah, W. Va., coal one-third of its volume in the same time.

These results are by no means to be interpreted as showing that some coals which yield little or no gas after mining are therefore not accompanied by gas in the mines. Pocahontas coal, for example, yields little methane after mining, but the mines in the western part of what is known as the Pocahontas district contain at times large quantities of gas. The methane which accumulates in coal mines may come, as before mentioned, from two sources—(1) from reservoirs of gas under pressure in the rock strata, and (2) from the coal bed itself, either from cavities where the gas has accumulated, or from a state of condensation or compression in the microscopic pores of the coal. The investigation discussed in this paper has to do only with the latter source, and although it advances data which emphasize the importance of the coal seam itself as a source of gas, it in no sense overlooks or lessens the importance of the inflow of gas from outside reservoirs.

It is known that variations in atmospheric pressure have an influence on the accumulation of methane in mines. Apparently incompatible with this fact are the results presented in this paper, which show that methane escapes from broken coal at a rate practically unaffected by large reduction in pressure. Atmospheric conditions, however, may easily affect the escape of gas from the bed of coal in situ, since a slight fall in barometric pressure may open communication with cavities or crevices in the coal bed where gas is imprisoned under pressure, although the same decrease of pressure may have little or no effect on the gas that is more intimately imprisoned in the pores of the solid coal.

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[a] Bull. Soc. chim., ser. 4, vol. 5, p. 380.

Carbon dioxide was found in the gases evolved by all the coals that were tested. The amount varied decidedly for the different coals; the maximum, from the Sheridan, Wyo., coal (No. 43), was 0.36 volumes in seven months. (See Tables 1 and 2, p. 10.)

PROCEDURE IN EXPERIMENTS.

A sample of approximately 10 kilograms (22 pounds) of the coal was taken from a clean, fresh face of the coal seam in the manner prescribed by the Bureau of Mines for mine sampling.[a] This sample was crushed so as to pass a ½-inch screen, and placed in a 5-gallon crated glass bottle, which was then stoppered as quickly as possible—usually within 50 to 80 minutes after beginning the cut. A tight-fitting rubber stopper was wired in. Through the stopper passed a 20-cm. (8-inch) length of glass tubing of 2-mm. ($\frac{1}{12}$-inch) bore, its outer end sealed by a piece of heavy rubber tubing and a solid glass plug. The crushed coal consisted largely of small lumps between one-tenth and one-half inch in size but contained 10 to 20 per cent of material under one-tenth inch in size. The bottle was shipped forthwith to the laboratory at Pittsburg. As soon as it arrived there the rubber stopper and connections were painted with shellac to avoid all risk of leakage, and a gas sample was at once withdrawn for analysis. The bottles were then allowed to stand in the laboratory several months at a temperature varying from 12° to 32° C.

Four coals, No. 37 (Pocahontas, Va.), No. 39 (Harrisburg, Ill.), No. 43 (Sheridan, Wyo.), and No. 49 (Benton, Ill.), were subjected to further investigation, as follows:

The bottle of Pocahontas coal (No. 37) was connected through the glass tube in the stopper to a reservoir of oxygen, so that the oxygen flowed into the bottle as fast as it was absorbed by the coal. From time to time the gas that accumulated in the bottle was drawn out in order to relieve the pressure and permit the inflow of oxygen. The bottles containing coals No. 39 and No. 43 were connected to a supply of air instead of oxygen and the inlet tube extended to the center of the coal in each bottle. There also was attached to each of these two bottles a collecting reservoir for the escaping gas, the connecting tube for this purpose passing from the top of the bottle to the reservoir. The bottle of Benton, Ill., coal (No. 49) was connected with both an oxygen supply and a gas-collecting reservoir; but oxygen, not air, was admitted to the bottle and was admitted at the top, the gas being withdrawn from underneath the coal.

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[a] Bureau of Mines Technical Paper 1, The sampling of coal in the mine, by J. A. Holmes. 1911. 18 pp.

The air, or oxygen, admitted was measured, and the gas withdrawn was measured and analyzed. Air, or oxygen, was admitted in slight excess so that every gas sample withdrawn contained some oxygen. It is hardly fair to compare the results of the test on Pocahontas coal with the results of the other tests, since in this test the accumulated gas was not withdrawn as regularly nor as rapidly as in the others and the pressure within the bottle may have retarded the escape of methane from the coal. The test, however, serves to show that this coal evolves a comparatively small quantity of methane. A number of other coals were tested in somewhat similar manner, occasional samples of gas being taken from the bottle but without drawing off the accumulated gas into collecting reservoirs or admitting a supply of oxygen. The tests made in this manner are named in Table 2.

The gas samples were analyzed by the Hempel methods with certain modifications, as described in Bureau of Mines Bulletin 1, pages 22 to 24. Methane was determined always by the slow combustion method of Winkler. No attempt was made to determine less than 0.2 per cent of carbon monoxide, and since the first samples from the bottles showed less than that quantity of carbon monoxide and also of hydrogen and unsaturated hydrocarbons, no determinations of these three constituents were made thereafter.

Descriptive list of coals tested.

Coal No.	Kind of coal.	State.	County.	Place.	Name of coal bed.	Mine.
29	Bituminous	Wyo	Sweetwater	Rock Springs	Rock Springs	No. 1.
30	do	do	Carbon	Hanna	Lower	No. 2.
33	Bituminous (cannel).	Ky	Johnson	Paintsville		Flambeau.
35	Bituminous	W. Va	Marion	Monongah	Pittsburg	No. 6.
37	Semibituminous	Va	Tazewell	Pocahontas	No. 3	Baby.
39	Bituminous	Ill	Saline	Harrisburg	No. 5	No. 9.
41	do	Pa	Fayette	Connellsville	Pittsburg	Leisenring No. 1.
43	Subbituminous	Wyo	Sheridan	Sheridan	No. 9	Dietz No. 2.
49	Bituminous	Ill	Franklin	Benton	No. 7	Hart-Williams.

TABLE 1.—*Gases given off and oxygen absorbed by four coals.*

Coal.	Weight of coal.	Period of time.	Gas removed.			Oxygen admitted.	Volume of gas relative to volume of coal.[a]	
			Carbon dioxide.	Oxy-gen.	Meth-ane.		Methane evolved.	Oxygen ab-sorbed.[b]
	Kilos.		*c. c.*	*c. c.*	*c. c.*	*c. c.*		
Pocahontas, Va. (No. 37).	13.4	First 31 days......	18	37	331	1,830	0.032	0.174
		Next 28 days......	0	7	95	4.010	.009	.390
		Next 31 days......	2	9	18	7,275	.002	.705
		Next 183 days.....	15	44	39	24,510	.004	2.375
		Next 31 days......	26	5	0	4,860	.0	.471
		10 months	61	102	483	42,485	.047	4.115
Harrisburg, Ill. (No. 39).	14.6	First 4 days.......	16	24	2,456	1,660	.218	.145
		Next 24 days......	0	0	1,370	0	.122	.0
		Next 31 days......	39	456	2,435	7,320	.217	.610
		Next 30 days......	0	102	1,407	2,744	.125	.235
		Next 153 days.....	340	363	4,185	17,460	.372	1.520
		Next 31 days......	218	181	330	4,040	.029	.343
		9 months	613	1,126	12,183	33,224	1.083	2.853
Sheridan, Wyo. (No. 43).	8.1	First 7 days.......	144	0	468	2,520	.075	.403
		Next 23 days......	57	52	486	1,550	.078	.240
		Next 31 days......	289	61	192	3,110	.031	.488
		Next 30 days......	350	54	0	2,940	.0	.462
		Next 92 days......	1,014	282	0	13,760	.0	2.157
		Next 31 days......	436	166	0	3,990	.0	.612
		7 months	2,290	615	1,146	27,870	.184	4.362
Benton, Ill. (No. 49).	12.2	First 15 days......	98	0	7,095	2,040	.763	.220
		Next 15 days......	0	34	1,051	4,610	.113	.494
		Next 62 days......	182	844	5,349	33,700	.577	3.532
		Next 30 days......	167	603	996	10,970	.107	1.113
		Next 31 days......	63	872	605	15,520	.065	1.576
		Next 365 days....	741	....	1,820	....	.196	....
		17 months	1,251	2,353	16,916	66,840	1.821	[c]6.935

[a] Relative volumes of gas are computed on the basis of the apparent specific gravity of the coal (taken as 1.3), this value being the average of a large number of determinations of small lump size (1-inch) coals made in the laboratory of the United States fuel-testing plant at St. Louis, Mo., in 1905 (U. S. Geol. Survey Bull. No. 323, pp. 23–24). The volume occupied by 10 kilograms of coal is therefore taken as $10 \div 1.3 = 7.7$ liters. The volume of the pores in small lump coal, assuming an average absolute specific gravity of 1.45, may be computed as one-tenth of the volume of the lumps; that is, $\frac{1.45-1.30}{1.45}=.103$.

[b] Oxygen from air in case of Nos. 39 and 43; from oxygen 95 per cent pure, in case of Nos. 37 and 49. See page 8. The great irregularities in the rate of absorption of oxygen are due to the irregular admission of oxygen, as explained on page 6.

[c] Total for five months only.

TABLE 2.—*Gases given off and oxygen absorbed by five coals.*

[Gas allowed to accumulate in a confined space.]

Coal No.	Period of time.	Gas evolved per 10 kilos of coal.		Oxygen absorbed.	Volumes of gas relative to volume of coal.	
		Carbon dioxide.	Methane.		Methane evolved.	Oxygen absorbed.
		c. c.	*c. c.*	*c. c.*		
29	First 22 days..................................	600	120	2,500	0.015	0.313
	Next 9 days....................................	4	0	0	....	....
30	First 10 days..................................	204	1,540	2,500	.192	.313
	Next 21 days..................................	14	265	0	.033	....
33	First 24 days..................................	650	0	2,500	0	.313
	Next 249 days................................	230	0	....	....	....
35	First 4 days....................................	0	3,190	2,300	.390	.288
	Next 26 days..................................	120	2,010	....	.251	....
41	First day..	135	....	1,080	....	.135
	Next 10 days..................................	155	980	1,220	.122	.153
	Next 415 days................................	16	300	....	.038	....

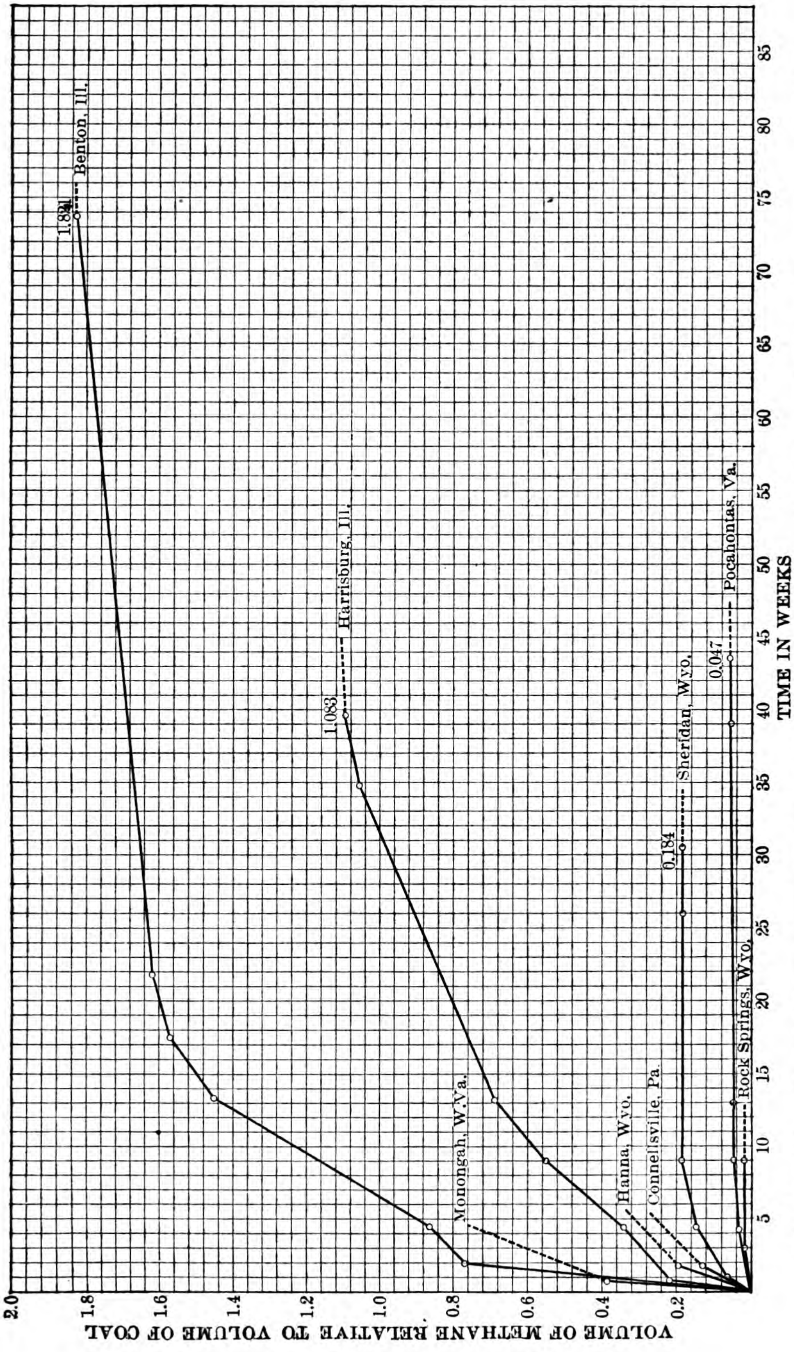

FIGURE 1.—Rate of escape of methane from coal. The time begins one hour after mining, hence the methane given off in mining is not included.

The difference in the rate of escape of methane from the coals is shown graphically in figure 1.

The results given in the tables and shown in figure 1 emphasize the gradual decrease in the rate of escape of methane and, in some cases, the ending of the liberation of methane within five months. The escape of methane from the two southern Illinois coals appeared to continue for a longer time, but even these coals showed a well-marked tendency to stop giving off gas. The dotted portions of the curves in figure 1 indicate the probable liberation of methane after the last measurement. The experiments with the coals from Monongah, W. Va., Hanna, Wyo., and Connellsville, Pa., were not carried far enough to show the rate of continuous escape of methane, but show the large quantity of methane set free by these coals just after mining. The coals from Rock Springs and Sheridan, Wyo., Paintsville, Ky., and Pocahontas, Va., do not appear to contain much inclosed gas. The results from the Harrisburg, Ill., coal (No. 39) are particularly instructive in showing, under conditions permitting good circulation of air, the gradually diminishing escape of methane, the long-continued absorption of oxygen, and in particular a steadily increasing liberation of carbon dioxide. This last phenomenon has been noted by Chamberlin,[a] and seems to indicate that either carbon dioxide is more tenaciously held in coal or, because of its greater density, does not diffuse as readily as methane. It is of interest to note in this connection the results from the Rock Springs and Sheridan, Wyo., coals and the Kentucky cannel coal, all of which yielded at the start greater quantities of carbon dioxide than the coals that were more highly charged with methane.

In a few instances, during the analysis of the hydrocarbons in the gases, a small proportion of ethane was indicated by the presence after combustion of slightly more carbon dioxide than accorded with the contraction in volume. But the quantities were so slight as to be within the probable limits of experimental error.

The rapidity with which the coals absorbed oxygen may be seen from the data on coals 43 (Sheridan, Wyo.) and 49 (Benton, Ill.) in Table 1, which show that in less than 15 days these coals had exhausted the oxygen from a volume of air equal to their own volume. In neither of these instances was the volume of carbon dioxide formed during the process greater than one-tenth of the volume of oxygen absorbed. That oxygen is probably taken into chemical combination rather than occluded or adsorbed by coal was shown by a simple experiment with the Benton, Ill., coal (No. 49). After being supplied with oxygen for five months, during which time it combined with oxygen equal in volume to nearly seven times its own volume of oxygen, a sample of the coal was placed in boiling water in a flask. The gases evolved during 15 minutes' boiling showed no excess of oxygen over that contained in air.

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[a] U. S. Geol. Survey Bull. 383, p. 30.

LOSS OF HEATING VALUE.

The largest volume of combustible gas evolved was from the sample of Benton, Ill., coal. From 12.2 kilograms of this coal, 16.9 liters of methane were evolved in one year and five months. If a calorific value for methane of 9,400 small calories per liter is assumed, there were lost by the 12.2 kilograms of coal $9{,}400 \times 16.9 = 158{,}860$ calories. As the heating value of the coal was about 7,500 calories, the percentage of loss was approximately $\frac{158{,}860}{12{,}200 \times 7{,}500} = 0.16$ per cent. It is evident, therefore, that no considerable loss of heating value can be attributed directly to the escape of combustible gases from coal during storage at ordinary temperatures.

CONCLUSIONS.

The results of the experiments discussed in this paper show that certain American coals, whose mining is attended with danger from accumulations of inflammable gas, liberate this gas not only while they are being broken down in mining, but also during a long period thereafter. At first the gas escapes rapidly, but the rate diminishes and tends toward a final cessation in 3 to 18 months. If the volume of the small lumps of coal used in the experiments be taken as the unit of measurement, about one-fourth volume of methane escapes during the crushing of the coal, as shown by Chamberlin, and one-half to one and one-half volumes on continued exposure to the air, as shown by the authors. The loss of fuel value by this loss of gas is small, but the danger of accumulation of explosive gas from this source in mines and in coal bunkers is sufficient to justify its being taken into account in the ventilation of mines and in the storage of coal.

PUBLICATIONS ON FUEL TESTING.

The following publications can be obtained free of cost by applying to the Director of the Bureau of Mines, Washington, D. C.:

BULLETIN 1. The volatile matter of coal, by H. C. Porter and F. K. Ovitz. 1910. 56 pp., 1 pl.

BULLETIN 2. North Dakota lignite as a fuel for power-plant boilers, by D. T. Randall and Henry Kreisinger. 1910. 42 pp., 1 pl.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp.

BULLETIN 4. Features of producer-gas power-plant development in Europe, by R. H. Fernald. 1910.

BULLETIN 5. Washing and coking tests of coal at the fuel-testing plant, Denver, Colo., July 1, 1908, to June 30, 1909, by A. W. Belden, G. R. Delameter, J. W. Groves, and K. M. Way. 1910. 62 pp.

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Bulletin 7. Essential factor in the formation of producer gas, by J. K. Clements, L. H. Adams, and C. H. Haskins. 1911.

Bulletin 8. The flow of heat through furnace walls, by W. T. Ray and Henry Kreisinger. 1911.

Bulletin 9. Recent development of the producer-gas plant in the United States, by R. H. Fernald. 1909. 82 pp., 2 pls. Reprint of Bulletin 416.

Bulletin 11. The purchase of coal by the Government under specifications, by G. H. Pope. 1911. 80 pp.

Technical Paper 1. The sampling of coal in the mine, by Joseph A. Holmes. 1911. 18 pp.